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Hecate Strait Project: Results from Four Years of Multispecies Fisheries Research

A. V. Tyler (Editor)

Department of Fisheries and Oceans
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Nanaimo, British Columbia V9R 5K6

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HECATE STRAIT PROJECT: RESULTS FROM FOUR YEARS OF MULTISPECIES FISHERIES RESEARCH

by

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ABSTRACT

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The Hecate Strait Project of the Pacific Biological Station, Biological Sciences Branch, was begun in April, 1984 and will continue through 1989. The goal of the project is to develop the ecological basis for approaches to mixed-species fisheries management in Hecate Strait. The landings from the area are important locally, but small on a world basis. The smallness is an advantage to research. The system is effectively a model of large scale situation that exist in many parts of the world that are more difficult to investigate, and whose fisheries are more difficult to manage. The 12 sub-projects that provide inter-related research results are as follows: Fish assemblage distribution surveys; Distribution of herring and pelagic associates in winter; Estimation of abundance and sizes of salmon species in the Strait; Feeding and summer distribution of herring and other pelagic fishes; Distribution and abundance of Hecate Strait benthos; Food-resource partitioning in four demersal fish assemblages; larval herring distribution; forecasting year-class strength of herring using environment-dependent stock recruitment models; Effects of transport, temperature, and stock size on recruitment of Pacific cod; Interaction between Pacific cod and herring in the Strait; the influence of size-at-first maturity on population productivity in Pacific cod.

RÉSUMÉ

Tyler, A. V. (Editor). 1989. Hecate Strait Project: Results from four years of multispecies fisheries research. Can. Tech. Rep. Fish. Aquat. Sci. 1675: 60 p.

Le Project du détroit d'Hécate de la Station biologique du Pacifique, Direction des sciences biologiques, a commencé en avril 1984 et se continuera en 1989. Le but du project est d'établir les fondements écologiques pour différentes stratégies de gestion des pêcheries à espèces mixtes du détroit d'Hécate. Les débarqements réalisés dans cette région sont importants au niveau régional, mais petits à l'échelle mondiale. Du point de vue de la recherche, il s'agit d'un avantage. Le système constitue un bon modèle de pêcheries à plus grande échelle qui existent dans de nombreuses parties du monde et qui sont plus difficiles à étudier et plus difficiles à gérer. Les 12 sous-projets qui fournissent des résultats de recherche interdépendants sont les suivants : relevés sur la distribution des assemblages de poissons; distribution du hareng et des poissons pélagiques associés en hiver; estimation de l'abondance et de la taille des espèces de saumons dans le détroit; alimentation et distribution estivale du hareng et d'autres poissons pélagiques; distribution et abondance du benthos dans le détroit d'Hécate; distribution des resources alimentaires dans quatre assemblages de poissons pélagiques; distribution du hareng larvaire; prévision de l'effectif des classes d'âge de harengs en utilisant des modèles de recrutement des stocks fondés sur l'environnement; effets du transport, de la température et de la taille du stock sur le recrutement de la morue du Pacifique; interaction entre morue du Pacifique et hareng dans le détroit; influence de la taille à première maturité sur la productivité de la population de morue du Pacifique.

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AN OVERVIEW

A. V. Tyler, Project Coordinator

General

The objective of the Hecate Strait Project is to conduct research into the ecological basis for multispecies stock assessment and management of herring, groundfish, and salmon in the Hecate Strait region. The project began in April 1984 and will terminate in March 1990. The research effort is divided among four horizontal habitat layers: the top layer dominated by salmonids and dogfish, the mid-layer dominated by herring and pelagic rockfish; the near-bottom layer - groundfish; and the sediments - invertebrate infauna.

The fishery in the region has many of the characteristics of mixed species fisheries in other temperate regions, with over 45 species taken by various gear types. Though the landings are important to the industry on the west coast of Canada, the fishery is small by world standards, with about 20 thousand tonnes being taken annually. This same smallness is an advantage to research, however, since the area is effectively a model of a mixed-species fishery, containing many of the complexities on a tractable geographic scale (120 x 50 nm), and with only a few hundred vessels catching fish (in fact less that 60 trawlers take most of the tonnage). Thus the findings of the project will have applicability to other areas of Canada and the world where it is far more expensive and time-consuming to gain the same insight.

Approaches to multispecies management being addressed

1. Assessment and management by critical species. Maintenance of the diversity of an entire assemblage may result from normal catch quota management of a small group of species. The persistence of all species in the area during the conduct of a valuable fishery is perceived as a legitimate goal. It is possible that simplifying the biological environment by large-scale decreases in minor species may lead to destabilization of the biomass of valuable target species.

2. Species interaction models. Modelling of selected interactions may give estimates of joint-species yields or give insight into particular management oriented questions, e.g., is there a cost to the herring fishery if there are twice as many juvenile salmon migrating through the Strait?

3. Management by Assemblage Production Units. Cohabiting, resident species with strong trophic linkages may have properties of integrated productivity that could be assessed to develop species-group quotas, and may be conceptualized as production units. These integrated quotas would not only allow persistent fishery yields while accounting for species interactions, but the group of species would be less difficult to manage than a plan wherein each species had a separate quota.

Sub-project organization

Research has been carried out under nine sub-projects by a number of researchers at the Pacific Biological Station, Nanaimo, B.C., and the Institute of Ocean Science in Sydney, B.C.

1. Distribution and abundance of benthos in relation to demersal fish assemblages. R. O. Brinkhurst, D. F. Moore, and B. J. Burd.

2. Analysis and distribution of demersal fish assemblages. A. V. Tyler, J. Fargo, and R. P. Foucher.

3. Food-resource partitioning by demersal fishes. A. V. Tyler and M. W. Saunders.

4. Larval herring distribution. D. E. Hay and P. B. McCarter.

5. Distribution of adult herring. D. E. Hay and P. B. McCarter.

6. Summer distribution and feeding of herring and associate species. D. E. Hay and P. B. McCarter.

7. Migratory use of the Strait by juvenile salmon. M. C. Healey and J. F. T. Morris.

8. Recruitment patterns in Pacific herring and Pacific cod. M. Stocker, A. V. Tyler, and W. R. Crawford.

9. Analysis of first maturity of Pacific cod. D. Welch and R. P. Foucher.

Some research highlights for the Project are summarized below:

1. The work on juvenile salmon biology in Hecate Strait dealt with the top water layer of the water column, in particular the five salmon species and associate fishes. The objective was to determine abundance, growth, and diet of the salmonids at selected sites, and to take preliminary data on other pelagic fishes of the top layer. Four charter trips with a commercial purse seiner in the summer of 1986 and 1987 revealed high abundances of juvenile salmon. A predictive computer model of juvenile salmon migration in the Strait tended to underestimate sizes of young chinook and coho. Hypotheses have subsequently been developed that could account for the discrepancies.

2. The main objective of the adult herring distribution study was to confirm the hypothesis that, after spawning, the herring disperse broadly in the Strait onto feeding grounds, and then congregate in more dense aggregations in the fall and winter in areas offshore from the well known spawning grounds. This study focused on mid-depth regions of the water column and included herring and associate fishes. The data from four winter survey cruises (Nov. 1984, Jan. 1985, Nov. 1985, Nov. 1987) using mid-water trawling and hydroacoustic techniques, allowed mapping of the

concentrations, and showed two major areas of aggregation: one on the mainland side of the Strait and the other on the Queen Charlotte Island side. These aggregations showed close correspondence to known spawning distributions. Two summer cruises (1985, 1987) indicated that the summer distribution was more dispersed than the fall-winter distribution, the densities in some areas being 10 times lower in summer.

3. Mapping and analysis of demersal fish assemblages was completed from two summer cruises (1984 and 1987), and one winter cruise (1986). Four assemblages were characterized statistically. These showed consistent geographic boundaries throughout the three cruises, despite summer to winter shifts in the distribution of some species.

4. A survey of infauna was conducted at four representative demersal fishery sites. A time series of samples was taken including June, September 1985, and February 1986. Faunas differed significantly among the sites, but were fairly constant through time. Factors associated with depth probably contribute to the differences. The infauna survey was conducted along with a food-resource division study of demersal fishes to examine trophic relationships among the fishes, and to address several hypotheses about diet selectivity. We will also use the food-resource division analysis to characterize and distinguish assemblage production units. Several thousand stomachs were preserved over a 3-year period (1985-87). Laboratory analysis is complete and development of the computer data base is complete.

5. Recruitment processes are being examined for herring and Pacific cod, two of the dominants in the Strait. Populations of both species are contained totally in the area. A survey for herring larvae provided a mapping of relative larval abundance that compared favourably with the known spawning areas, and indicated substantial transport along the east and west coasts of the Strait, but not through the middle, deepwater areas. Herring and cod recruitment patterns over a 20-year period were studied with statistical fitting techniques. Above-average herring year-classes tended to be associated with warmer sea surface temperatures following spawning, while increased Pacific cod recruitment was related to decreased northward transport through the Strait when the fish were in larval stages. Adult stock size was also influential. Juvenile herring and adult cod showed a reciprocal relationship through a twenty-year period, giving support to a predator-prey relationship between the two species that may at times influence the stock sizes of both.

AUTHORS' SUMMARIES OF RESEARCH RESULTS

R. O. Brinkhurst, B. J. Burd, and D. F. Moore

Distribution and abundance of benthos in relation to demersal fishes

A study of the benthic infauna was carried out in conjunction with the stomach-content and species assemblage work of the Groundfish Section. On the first cruise (June 7-17, 1985) three areas were sampled (A-C) but on the second and third cruises (Sept. 23 - Oct. 4, 1985 and Jan. 27 - Feb. 8, 1986) a fourth area (D) was included (Fig. 1, Saunders and Tyler, this document). The sampling design involved obtaining a single sample from each of the four corners of each rectangular area and one in the middle, plus two sets of five replicate samples at two other spots within each area (Fig. 1). Samples were obtained with a Smith-McIntyre grab and were screened through a 1 mm mesh. Samples were preserved in the field, stained with Borax Carmine, and sorted in the laboratory. All taxa present were identified as far as was practical, which means to species for the major groups. Residues from the sorting were checked for quality control. Wet weights of the fauna were obtained using specimens preserved in isopropanol. Particle sizes of sediment samples were also determined.

The resulting data matrices were analysed by means of cluster analysis (Bray Curtis/WPGMA). Cluster analyses were examined for internal significance of clusters and between cluster variation (different places, different times). The faunas of each area differed from each other, as might be expected, but the results from the three cruises showed no significant differences due to time. Depth and geographic distance between stations accounted for more of the significant differences between the four areas than particle size as determined by us. Natural silt structure may be strongly affected by the analytical procedures used to determine particle size, and so features of the silt important to animals may be lost in the process. Wet weight data was much more variable than the numerical data on species abundance (Burd and Brinkhurst 1987).

This information will soon be compared with the fish species-assemblage data and the fish stomach analyses to test several hypotheses related to fish food availability and utilisation.

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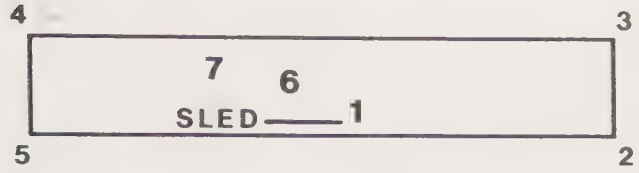
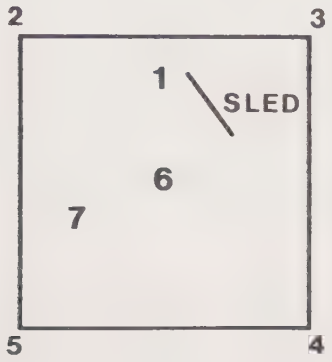
Fig. 1. Benthos sampling scheme. The numbers on the rectangles indicate sample sites. Distances are in nautical miles (N.M.). The location of the four areas in Hecate Strait is shown in Figure 1 of Saunders and Tyler, this report.

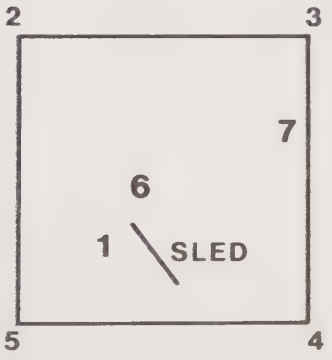
AREA A 1×6 (Nautical Miles)^2



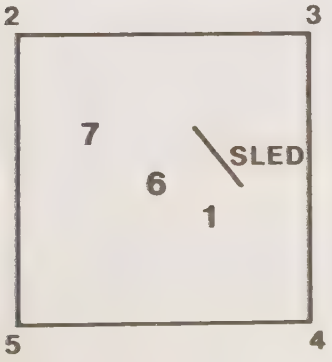
AREA B 3×3 (N.M.)^2



AREA C 3×3 (N.M.)^2



AREA D 3×3 (N.M.)^2



J. Fargo and A. V. Tyler

Distribution of demersal fish assemblages

Since the original May 1984 species assemblage survey (Fargo et al. 1984; Westrheim et al. 1984; 1986; Fargo and Tyler 1986), two additional assemblage surveys (one winter and one summer) have taken place (Fargo and Davenport 1986; Fargo et al. 1988; Foucher et al. 1988). The original survey was intended to provide synoptic survey data that would lend itself to a mapping of fish assemblages available to bottom trawlers. Data from the additional surveys was intended to provide some estimate of inter-seasonal and inter-annual variability in the assemblages previously defined (Fargo and Tyler 1986). Future surveys will establish a time series of catch data so that fishery effects on these assemblages can be examined.

Maps of the stations fished in each of these surveys are presented in Figures 1 and 2. The 1986 winter survey was a two-vessel operation involving one chartered and one research vessel, while the 1987 summer survey was a one-vessel survey.

The clustering approach for this data was the same as that for the 1984 survey data (Fargo and Tyler 1986). A Bray-Curtis dissimilarity index was used and then a group average fusion strategy was applied.

Some fishing effort of the survey was expended in southern Hecate Strait in an area inhabited by various species of rockfishes. These species were assumed to make-up a distinct assemblage for purposes of comparison in our analysis. All of the survey data was subjected to cluster analysis. When we examined the grouping of these rockfish species we found that they clustered out at a dissimilarity level of 0.7. We then examined other clusters created at this level of dissimilarity. For example, from the 1987 survey data we defined 7 sub-groups (clusters) of fish species at the 0.7 dissimilarity level (Fig. 3). Further analysis revealed that the dominant species of some of the sub-groups were the same. They differed only in the relative abundance of the different species. We then combined the sub-groups with similar species composition. This resulted in 4 fish-assemblages. The distribution of haul locations within each of the 4 assemblages is depicted in Figure 4. The assemblage boundaries correspond roughly to the bathymetry of Hecate Strait. We named the fish assemblages Reef Island, Butterworth, Bonilla, and Moresby Gully after dominant geographical landmarks associated with them.

The assemblages were distributed by area and depth in a similar manner to those from the 1984 survey (Figure 2.2, Fargo and Tyler 1986). Depth distribution of the trawl hauls within each assemblage is shown in Figure 5. Relatively discrete depth strata were characteristic of each assemblage. Relative abundances of species by biomass in each assemblage are listed in Tables 1 and 2 by survey.

A brief description of each assemblage with regard to bathymetry and species distribution and composition is contained in the paragraphs below.

The Reef Island assemblage is located in central Hecate Strait, predominantly in the 10-40 fathom depth range. Principal species are rock sole, big skate, and Pacific halibut. Spiny dogfish is present as a seasonal species (summer) in this assemblage.

The Butterworth assemblage is located in northern Hecate Strait in the 30-70 fathom depth range. Principal species are ratfish, arrowtooth flounder, and English sole. Seasonal species in this assemblage are Dover sole (summer) and spiny dogfish (winter).

The Bonilla assemblage is located in central Hecate Strait in the 30-70 fathom depth range. Principal species are Pacific cod, English sole, Pacific sanddab, and rex sole. Seasonal species in this assemblage are spiny dogfish and arrowtooth flounder (winter).

The Moresby Gully assemblage is located adjacent to Moresby Gully in depths greater than 70 fathoms. Principal species are Pacific ocean perch, rougheye rockfish, silvergray rockfish, and arrowtooth flounder. Dover sole is a seasonal species (summer) in this assemblage.

Overall, fish-assemblages remained fairly stable from year to year, although seasonal bathymetric migrations were observed for some species, such as Dover sole and spiny dogfish. In contrast to this, Pacific sanddab and rex sole showed remarkable stability in abundance and distribution over the study period (Figure 6). A change in relative abundance was also noted for several species. Pacific cod underwent a dramatic increase in abundance due to an increase in recruitment since the 1984 survey. Arrowtooth flounder, and Pacific halibut and rock sole appear to be increasing in abundance over this time period evidenced as well by higher catch rates for these species on the 1987 survey compared to the 1984 survey.

In summary, the species assemblages in the Hecate Strait region are characterized by their depth ranges. Within assemblages we can now describe regular and seasonal or occasional components. Past studies have considered that production processes of species that are regular components of an assemblage unit are driven by effects of species moving occasionally or seasonally through an area. When results of analysis of stomach content data collected are available, trophic linkages among components of assemblages can be established and production processes can be postulated. The effects of the fishery vs natural effects on assemblages will be examined using fishery data and a proposed time series of assemblage survey data. Finally, multispecies harvest strategies will be proposed for the region.

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Table 1. Species assemblages in Hecate Strait based on trawl surveys conducted by F/V DOUBLE DECKER and FR/V G.B. REED, February 1986.

Species	Relative abundance of biomass
Reef Island	
Rock sole	33%
Ratfish	22%
Big skate	17%
Pacific sanddab	6%
Butterworth	
Ratfish	40%
Big skate	16%
Pacific cod	15%
Arrowtooth flounder	11%
English sole	6%
Bonilla	
English sole	34%
Rex sole	13%
Pacific cod	11%
Big skate	7%
Pacific sanddab	7%
Arrowtooth flounder	6%
Moresby Gully	
Spiny dogfish	36%
Silvergray rockfish	13%
Arrowtooth flounder	12%
Pacific ocean perch	10%
Redbanded rockfish	8%

Table 2. Species assemblages in Hecate Strait based on a trawl survey conducted by the F/V EASTWARD HO, May - June 1987.

Species	Relative abundance of biomass
Reef Island	
Spiny dogfish	58%
Rock sole	11%
Big skate	10%
Pacific halibut	10%
Lingcod	6%
Butterworth	
Arrowtooth flounder	58%
Dover sole	10%
Ratfish	9%
Spiny dogfish	6%
English sole	5%
Rex sole	4%
Bonilla	
Pacific cod	44%
English sole	21%
Spiny dogfish	7%
Pacific sanddab	4%
Arrowtooth flounder	3%
Pacific halibut	2%
Ratfish	2%
Rex sole	2%
Walleye pollock	2%
Moresby Gully	
Pacific ocean perch	53%
Arrowtooth flounder	14%
Redbanded rockfish	7%
Dover sole	6%
Yellowtail rockfish	2%
Silvergray rockfish	2%

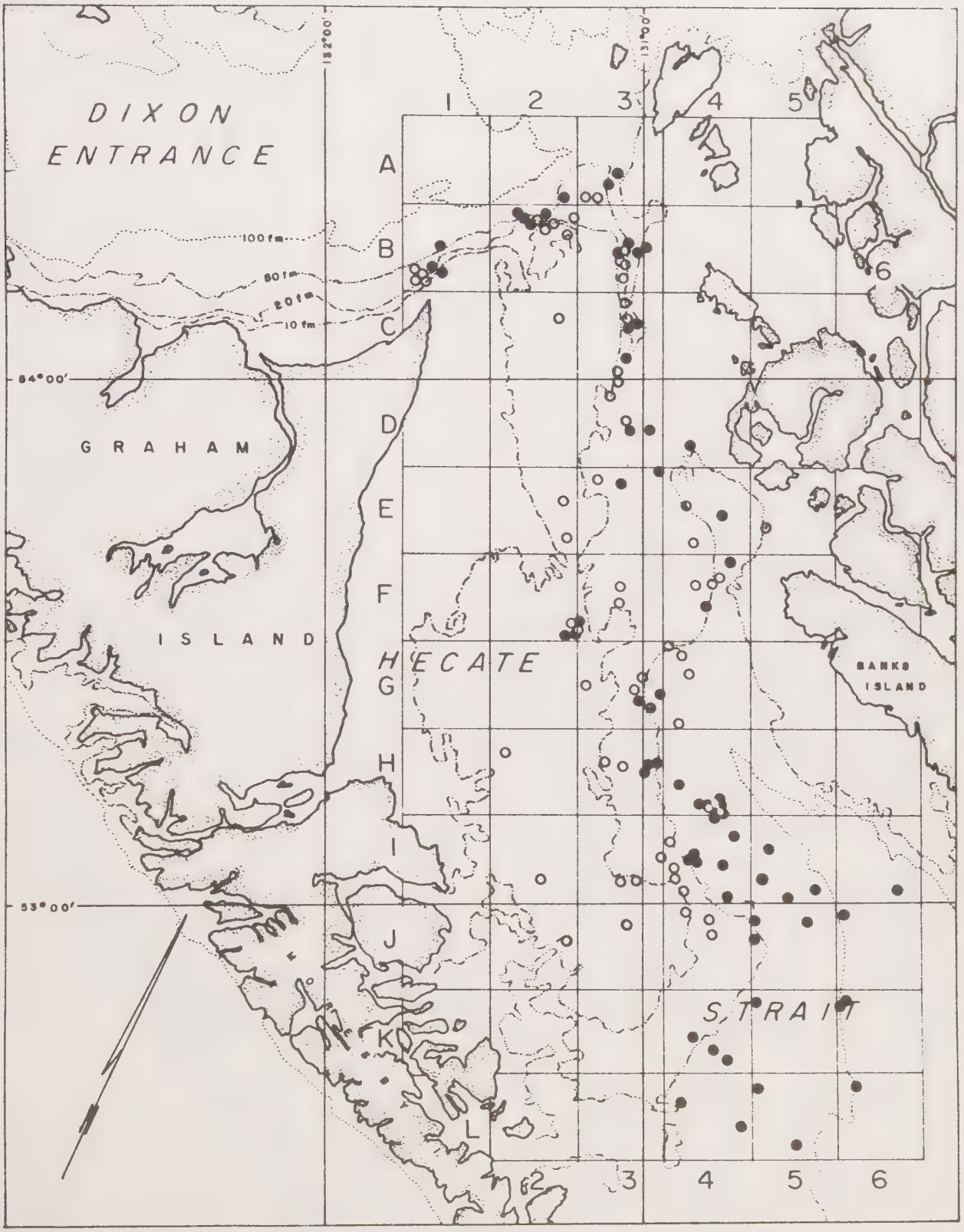

Fig. 1. Haul locations of the 1986 winter assemblage survey of Hecate Strait. Solid dots represent R/V G.B. REED haul locations, while open circles represent F/V DOUBLE DECKER haul locations.

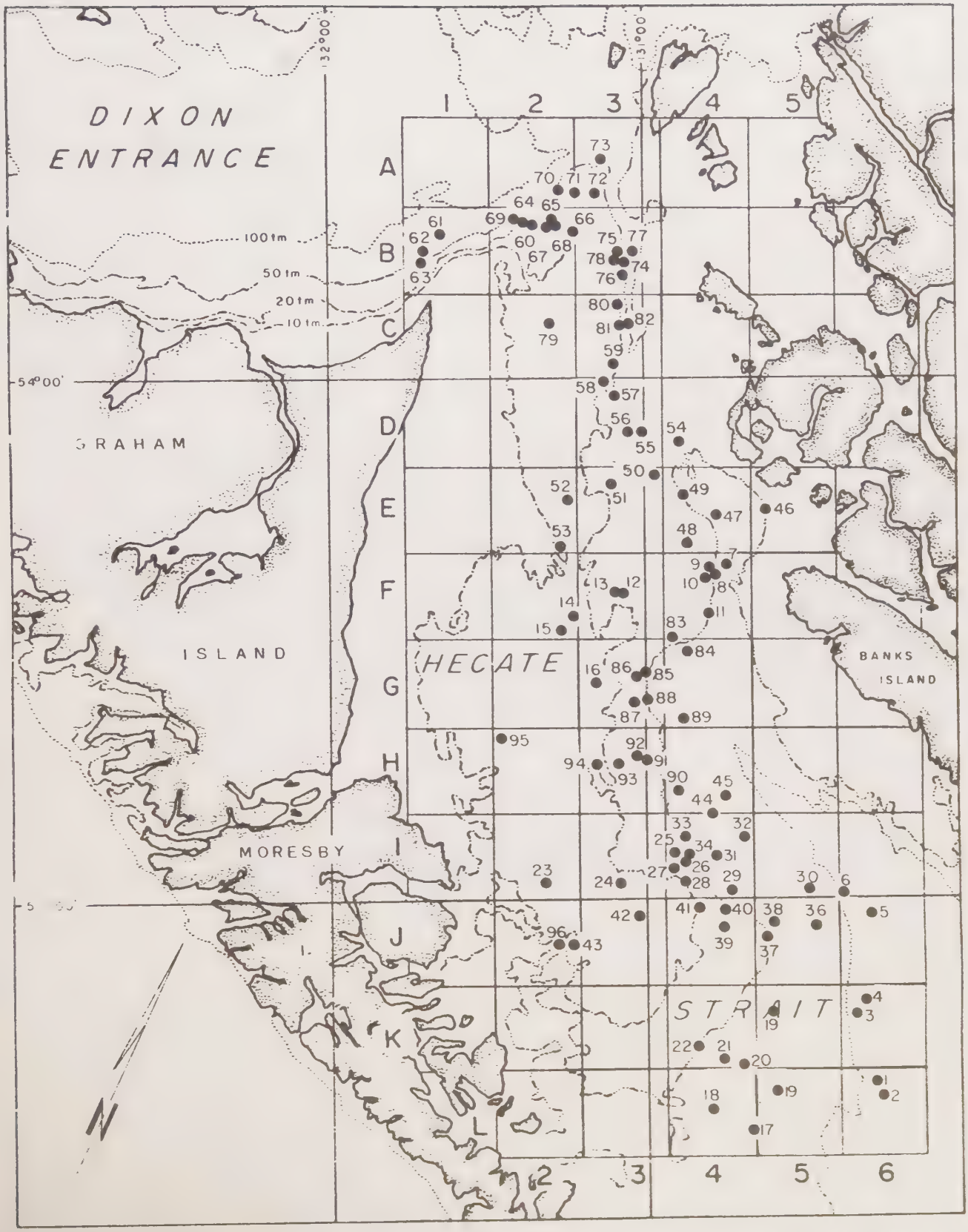

Fig. 2. Haul locations of the 1987 summer assemblage survey of Hecate Strait, F/V EASTWARD HO.

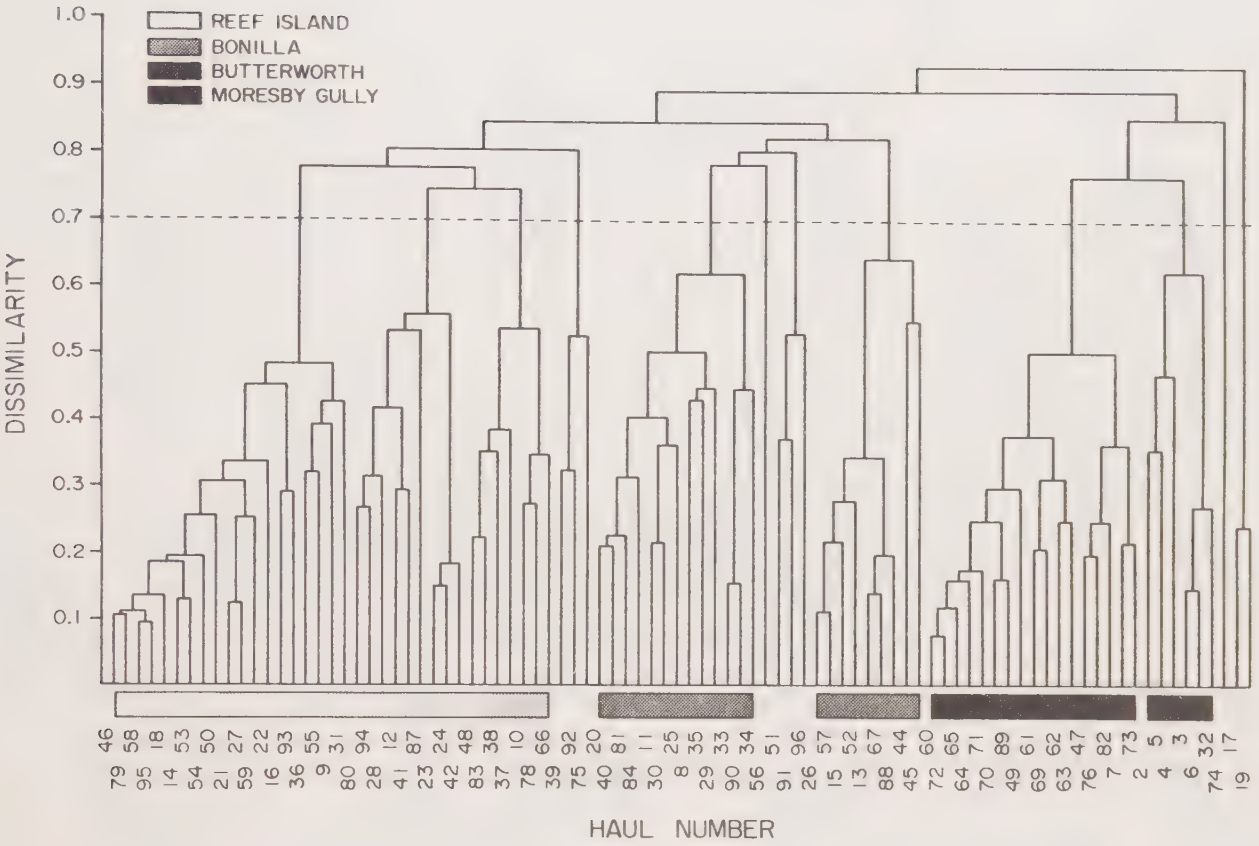

Fig. 3. Dendogram for the 1987 summer assemblage survey showing the sub-group combinations for the four Hecate Strait assemblages.

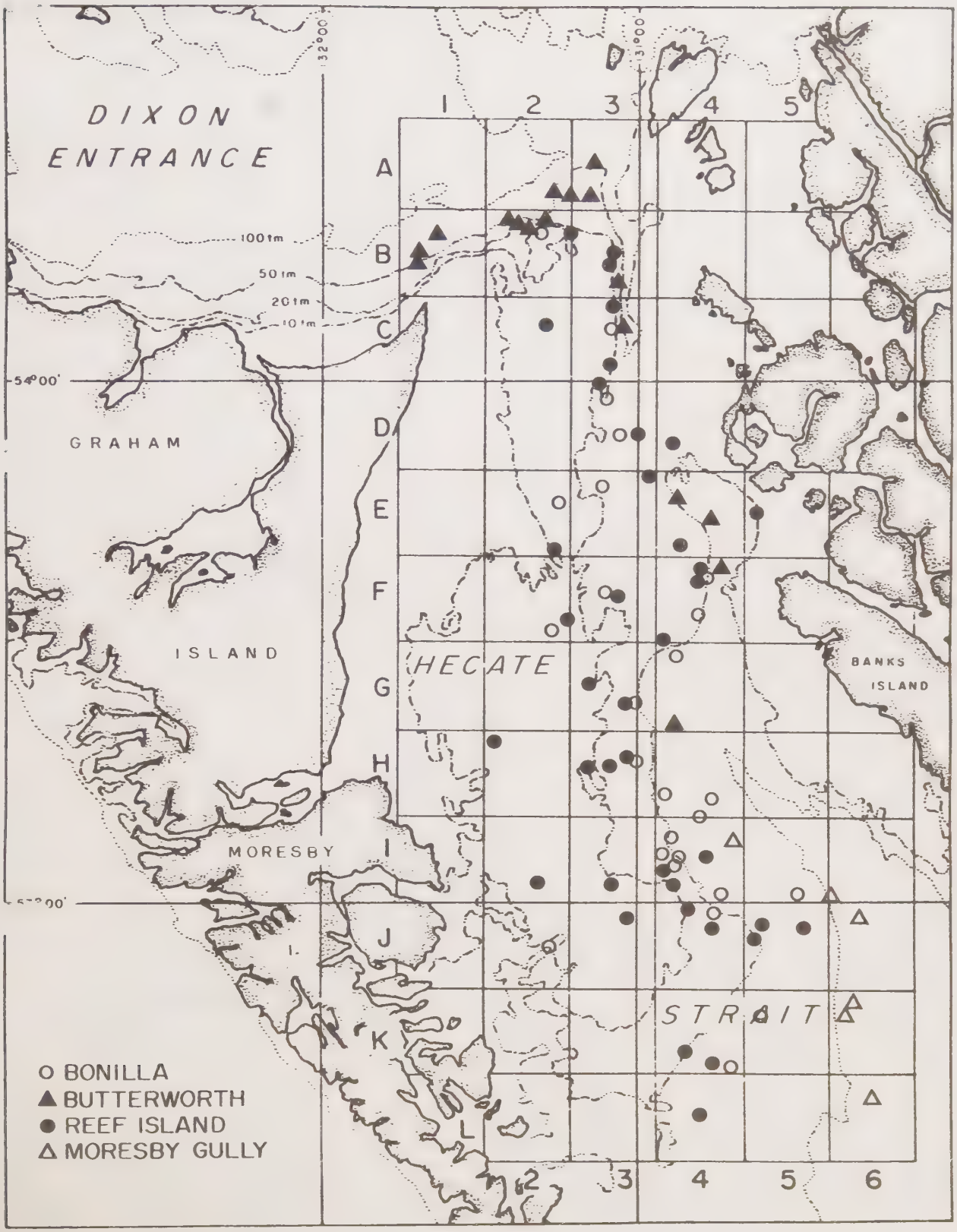

Fig. 4. Distribution of hauls combined in cluster analysis with regard to species assemblages.

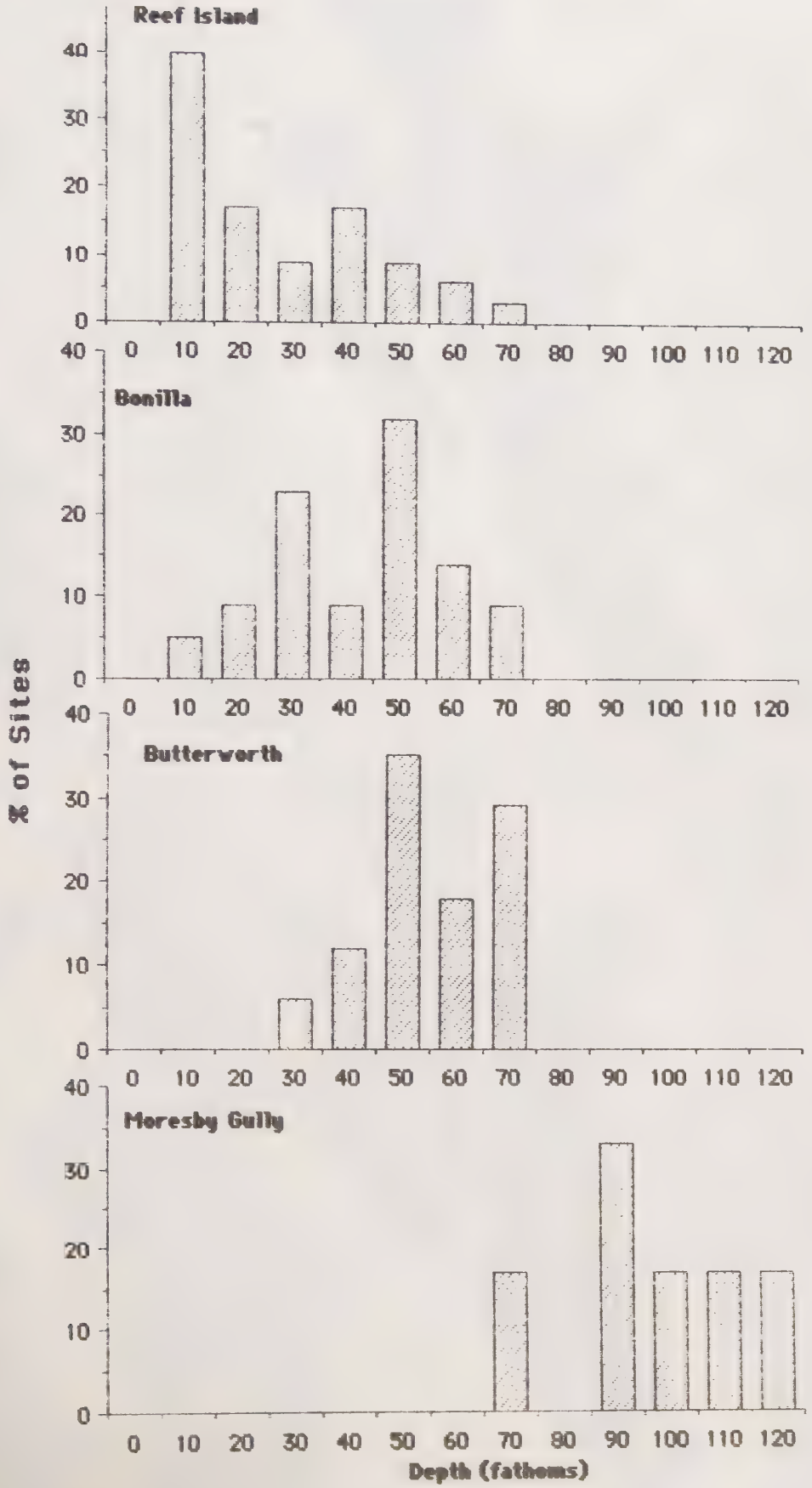

Fig. 5. Depth distribution of hauls in the four assemblages in Hecate Strait.

Fig. 6. Seasonal distribution and density of Pacific sanddab and spiny dogfish, based on the 1986, 1987 assemblage surveys of Hecate Strait. Haul locations are shown as white points.

PACIFIC SANDDAB
SUMMER
PACIFIC SANDDAB
WINTER
SPINY DOGFISH
SUMMER
SPINY DOGFISH
WINTER

Fig. 6.

M. W. Saunders and A. V. Tyler

Food-resource division by demersal fishes

The primary goal of this study is to establish and compare the patterns of food resource division among abundant groundfish species within assemblage production units in Hecate Strait (see Overview this document for definition; also Tyler et al. 1982).

The field portion of this study is now complete with stomachs collected from cruises in June 1985, September 1985, February 1986 and June 1987. Cruise reports for the 1985 sampling trips are reported by Saunders et al. 1986. Reports for the other two cruises are currently in preparation. The first three cruises will provide a within-year, seasonal comparison, with the fourth cruise providing an interannual comparison.

During each of these cruises, stomachs were sampled from four areas deemed to be representative of the assemblages present in Hecate Strait. During February 1986, a total of 1389 stomachs were collected and preserved from 24 species of groundfish while during June 1987, 605 were collected from 19 species (Tables 1 and 2). Stomachs were preserved only from fish with food in their stomachs. Fish length was recorded with each preserved stomach to provide information on diet shifts with increasing predator size.

Benthic grab and epibenthic sled samples were collected by staff of the Ocean Ecology section of the Institute of Ocean Sciences, Patricia Bay, during all but the June 1987 cruise. These samples will provide an index of prey availability and allow comparisons of prey abundance among stations.

Laboratory analysis of gut contents is now complete. Prey items were identified to species, when possible, and information on prey digestion state, number and weight was recorded. Analysis of results is currently underway.

Some hypotheses addressed by this study regarding predator-prey relationships are as follows:

Hypothesis 1. Regarding relative abundance in stomachs and sediment. Prey relative abundance in the stomachs is the same as abundance in the sediment.

Implies that prey is not selected.

Hypothesis 2. Regarding quantities of a prey item consumed. Abundances of a single prey taxon in stomachs and in sediment are independent of one another.

Implies that quantity eaten is not responsive to quantity in sediment.

Hypothesis 3. The greater the abundance of a prey species in the substrate, the greater the number of predator species that take the prey species as a principal prey.

Implies that diet overlap is due to superabundance of prey.

Hypothesis 4. As predator size increases, so does prey size.

The implication is that selection by prey size is a resource partitioning mechanism.

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Table 1. Full stomachs collected and preserved, by species, during the G.B. REED cruise of the food-resource division study, February 1986.

Species	No. of stomachs
Arrowtooth flounder	226
Curlfin sole	1
Dover sole	1
English sole	268
Flathead sole	11
Pacific halibut	14
Petrale sole	48
Rex sole	124
Rock sole	18
Sand sole	5
Speckled sanddab	2
Pacific sanddab	69
Butter sole	2
Sebastes flavidus	18
S. paucispinis	1
Eulachon	10
Lingcod	16
Pacific cod	251
Walleye pollock	40
Black skate	2
Ratfish	197
Big skate	21
Male spiny dogfish	8
Female spiny dogfish	36
Total	1389

Table 2. Full stomachs collected and preserved, by species, during the MV EASTWARD HO cruise of the food-resource division study, June, 1987.

Species	No. of stomachs
Arrowtooth flounder	50
Dover sole	50
English sole	112
Flathead sole	4
Pacific halibut	18
Petrale sole	3
Rex sole	67
Rock sole	18
Sand sole	3
Pacific sanddab	26
Sebastes sp.	15
Lingcod	1
Pacific cod	84
Sablefish	7
Walleye pollock	32
Big skate	1
Black skate	2
Ratfish	58
Spiny dogfish	54
Total	605

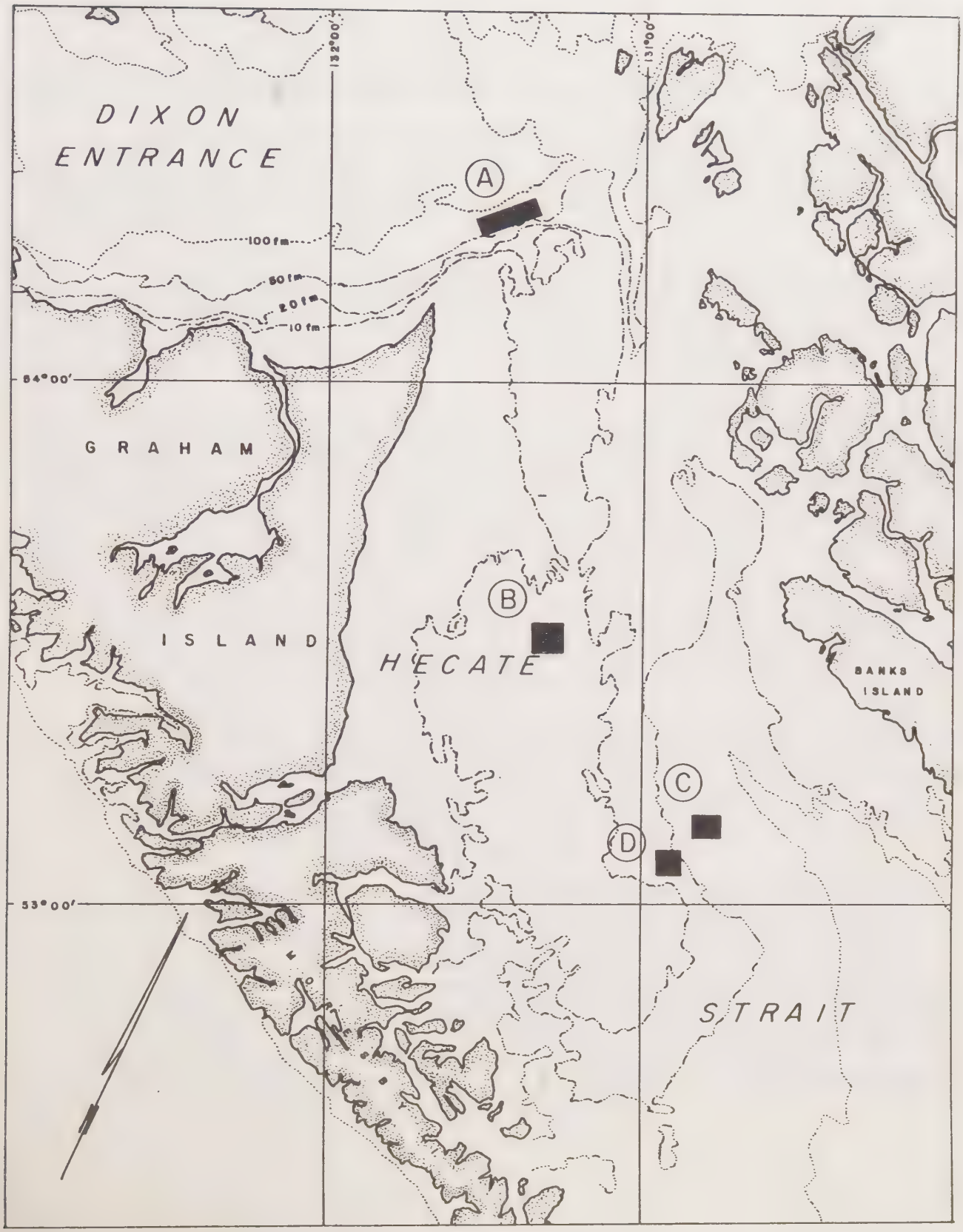

Fig. 1. Stomach sampling locations; A, B, C, D.

D. E. Hay and P. B. McCarter

Larval herring and other larval fishes in Hecate Strait

Surveys of larval herring were made in 1985 and 1986, approximately 3 weeks after the completion of the major spawning activity in early spring. Subsequent to the field collections the samples of larval herring and other larval fishes have been analyzed in the laboratory, with assistance from summer students.

Sample analysis was completed in the fall of 1987. The data have been keypunched and are presently under analysis using statistical programs on the VAX computer. The following summaries are preliminary, but should be approximately representative of the results to be presented more fully in a later report.

The larval surveys were concentrated in the general vicinity of the three largest northern herring spawning areas: (1) Kitkatla to Porcher Island; (2) Big Bay to Port Simpson in Chatham Sound; (3) the Southern Queen Charlotte Islands, particularly Juan Perez and Skincuttle Inlets (Figure 1). The samples were made with 0.5 square meter bongo nets hauled from the research vessel G.B. REED in deeper water locations and with 0.2 m bongo nets hauled from smaller (6 m) vessels in shallow water locations.

1. The distribution of larvae appears to be confined mainly to near-shore locations (Figure 2). In general there was more dispersion of larvae along the coast than there was to deeper, offshore locations. Almost no herring larvae were taken in mid-Hecate Strait.

2. The distribution of larvae between the two major north-coast spawning locations, Kitkatla Inlet or Porcher Island and Chatham Sound, was continuous in both years (Figure 1). The relevance of this observation is that, by virtue of the mixing of larvae between the adjacent but geographically separate spawning sites, there probably is only a single large stock on the northern mainland coast.

3. All fish larvae captured in 1986 were smaller than those taken in 1985. The significance of this observation is not clear at the present time. The difference in sizes in herring larvae was observed both in the estimates of mean length and mean weight. The difference cannot be attributed to difference in larval ages because the two surveys were made approximately in the same times each year and, in the case of herring, we have estimated larval ages by comparing time of capture with the date of spawning, recorded by Fishery Officers. The larval ages were approximately similar each year. The implications of these observations will be discussed more fully in a later report.

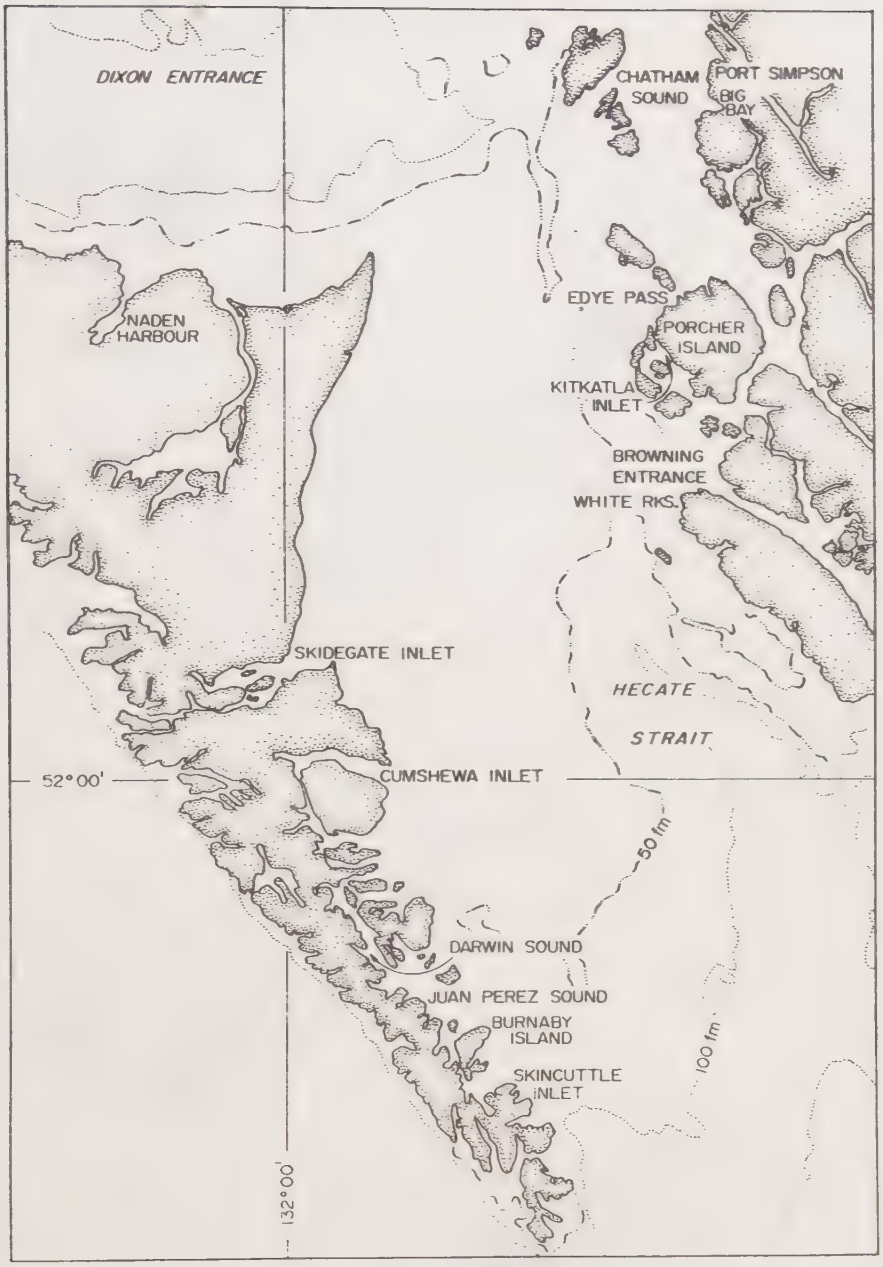

Fig. 1. Localities described in the text.

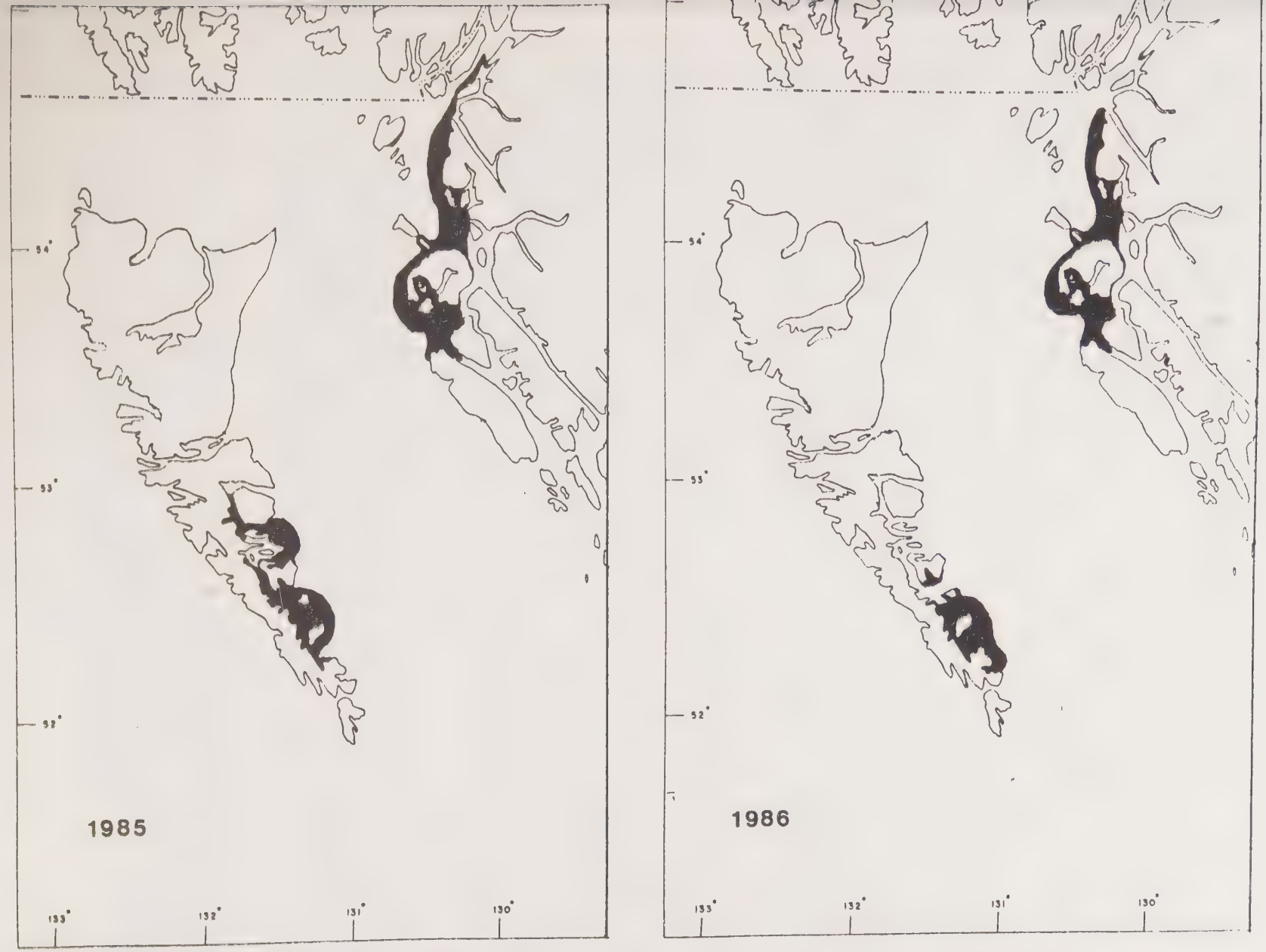

Fig. 2. The approximate distribution of herring larvae (dark area) in the northern B.C. coast and the southern Queen Charlotte Island coast in 1985 and 1986.

D. E. Hay, P. B. McCarter, and R. Kieser

Winter distribution, hydroacoustic biomass estimation and biological analyses of Pacific herring in Hecate Strait

Studies of the offshore distribution and abundance of herring in Hecate Strait began with a research cruise in November, 1984. This was followed by cruises in January 1985, November 1985 and November 1987. Reports for the first three cruises have been published in the Manuscript and Data Report Series. The report for the 1987 cruise is completed except for the inclusion of data on herring ages, which will be available later.

Initially, the work was conducted with two specific objectives. One was to document the distribution of herring in the winter. In general the Pacific herring life cycle involves movement or migrations between summer "feeding grounds" inhabited from about April to October, winter "holding areas" occupied from about October to February and "spawning areas" used in March and April. Prior to this work the specific winter sites were not well documented. The results of the work have confirmed that Browning Entrance is a major wintering area for herring spawning on the northern mainland side of Hecate Strait. Also, Juan Perez Inlet was shown to be the major wintering area used by a large stock of herring in the southern Queen Charlotte Islands.

No other large winter herring concentrations were found, even with extensive searching, both in nearshore and offshore locations. However, searches were not been made in adjacent Alaskan waters. The Juan Perez concentration was observed in January 1985, November 1985 and November 1987. This general location corresponds, roughly, to the largest spawning location on the Queen Charlotte Islands, extending from the northern part of Juan Perez Inlet (Darwin Inlet) south to Skincuttle Inlet (Huston Inlet). There also are some smaller, distinct winter concentrations of herring on the Queen Charlotte Islands that have been observed during these surveys and previous surveys in the 1970s. In general there is a close correspondence between the spawning distribution and winter distribution although the biological distinctness of each stock is not clear at this time.

A second objective of the work was to examine the feasibility of making hydroacoustic biomass estimates of herring when they are in dense winter concentrations. Making such estimates depends first on knowing the approximate locations of winter concentrations and being able to make mid-water trawl catches to confirm species identification. Biological data on the size and maturity of herring were collected as well.

The results of the hydroacoustic analyses in this research are encouraging but not definitive. The main factors affecting the accuracy and utility of hydroacoustic surveys are (1) the likelihood of finding herring in predictable, well defined locations and (2) the repeatability, over time, of the surveys within confined areas. Confinement of herring to a few major winter holding areas eliminates the requirement of having to make expensive, time-consuming, geographically widespread synoptic surveys.

Hydroacoustic biomass estimates also are affected by the mobility of the fish - if fish move rapidly about within the winter holding areas, then attempts to survey the biomass of the moving fish will be confounded. On the basis of the analyses done to date, we conclude that the mobility of herring within the holding areas may be a problem but perhaps not an insurmountable one. For instance, repeat hydroacoustic surveys of small, distinct, concentrations shows striking differences in biomass estimates made over a 24-hour cycle. In general, estimates were more similar within daytime or nighttime periods than they were between daytime and nighttime.

Offshore herring surveys show promise as a way of obtaining stock abundance estimates that are independent of fishery statistics. Also, offshore surveys can be done before the spawning season so that abundance estimates could be used as "in-season" estimates, rather than the "after-the-fact" estimates based on spawning escapement. Biomass estimates made for the 1984 Browning Entrance herring in the winter (about 30,000 tonnes) corresponded closely with stock estimates made by other methods for 1985 spring spawning herring. Similar results were found between the November 1985 survey and the biomass estimated from the March-April 1986 spawning stock. The similarity of the two estimates may have been coincidental and further surveys are required to establish the reliability of hydroacoustic methods.

In 1987 overwintering herring were concentrated in the same areas as previous surveys. Biomass estimates were estimated to be close to those of previous years but we experienced severe target calibration difficulties, mainly associated with the changes of vessels and sounding equipment between this and previous surveys. This difficulty may prevent a direct comparison of the 1987 biomass estimates with those of previous years or with the biomass estimates made by other methods.

In addition to the two specific objectives established for this work, we have made some observations about the winter ecology of herring, specifically on their feeding. In November 1987 stomachs of herring were collected and fixed for later analysis of contents in the laboratory. These analyses are not yet completed but we can confirm that herring were indeed feeding in November. This observation challenges the notion that herring move between summer feeding grounds and winter areas where they are more or less sedentary while undergoing sexual maturation. Instead we suggest that the distribution of herring in the winter may, like the summer distribution, reflect the abundance of food organisms or predators or both. In this regard, experimental analyses of impounded herring indicate that herring must eat over the winter to avoid excessive weight loss, perhaps 15-20%, between November and March (Hay et al. 1988).

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Fig. 1. Distributions of pre-spawning herring during winter surveys.

P. B. McCarter, R. Kieser, and D. E. Hay

Feeding and summer distribution of herring and other pelagic fishes in Hecate Strait

Two research cruises were made in the summers of 1985 and 1987 to investigate the distribution and feeding ecology of herring and other pelagic fishes in Hecate Strait. The second trip was originally scheduled for July 1986 but plans were changed when the new research vessel (W.E. RICKER) replaced the older G.B. REED. This change in vessels had an impact on our capacity to replicate the work. In 1985 there were more plankton samples but fewer trawling samples than in 1987. Also, in 1987 we included some hydroacoustic analysis. The intent of the hydroacoustic work was to examine the hypothesis than the relative density of herring in the summer was less than that in the corresponding winter surveys. This would be expected if the distribution of herring is determined largely by the availability of food.

In both surveys coastal waters within the 50-200 m bottom contour of Hecate Strait were surveyed to determine Pacific herring distribution patterns. In 1987 midwater biomass (all species) estimates were 3,300 metric tonnes (t) at Two Peaks-Butterworth edge, 1,140 t at Browning Entrance, 1,090 t SW of Bonilla Island, 570 t at the Horseshoe grounds and 1,320 t off Ramsay Island. Midwater species assemblages of pollock, dogfish and herring precluded separate estimates of herring biomass. The obvious weakness in these estimates is that target strength varies among species so, strictly speaking, these estimates of total biomass are crude at best. On the other hand, they do illustrate that herring biomass in the summer is lower in the same areas than it is in the winter. The presumed explanation for this is that the distribution of herring is broader in the summer because the distribution of food organisms is broad.

In 1987 the species composition of five midwater trawl and 66 bongo net catches, stomach contents and size and age distribution of herring were also examined and oceanographic data were collected at nine hydrographic and plankton stations. The plankton sample analysis was completed in March 1988 and the data are presently under analysis. Biological data from the herring samples will be done, under contract, as part of the routine herring sample analysis for monitoring of the fishery. Data from these samples will be available in the summer of 1988. At that time the cruise report for the 1987 cruise will be completed and scientific reports will be prepared.

M. C. Healey and J. F. T. Morris

Catches of juvenile salmon and other pelagic fishes in Hecate Strait and comparison with predictions of a migration model

The objective of the juvenile salmon project within the Hecate Strait program is to determine the abundance, residency, growth, and food requirements of juvenile salmon in Hecate Strait. In the first stage of this study we constructed a coastal migration model for juvenile salmon that predicted these parameters under various assumptions about juvenile migratory behaviour, growth, and mortality (Healey 1986). During July and August 1986 and 1987 we sampled juvenile salmon by purse seine in southeastern Hecate Strait to test predictions of the model. The sampling periods were chosen to provide the best opportunity to distinguish among the alternate assumptions about juvenile migratory behaviour used in the model. We report some results of that sampling here.

Pink salmon dominated the catch in both years, followed by chum. Sockeye and coho were less abundant and chinook comparatively rare in the catch (Table 1). Only five species other than salmonids were captured herring, Clupea pallasi; dogfish, Squalus acanthias; yellowtail rockfish, Sebastes flavidus; black rockfish, Sebastes melanops; sablefish, Anoplopoma fimbria), and none was abundant (Table 1).

Species and size composition of juvenile salmon in the catches were compared with predictions of the model assuming that all juveniles from south of Hecate Strait migrate north through the Strait. This assumption gives the best fit to the observations. In 1986 observed and predicted species composition were similar, although the model underestimated the relative abundance of pink salmon and overestimated the relative abundance of chum and sockeye (Table 2). In 1987 pink salmon were much more abundant than predicted, particularly in August (Table 2). Pink salmon should have been relatively rare in Hecate Strait by mid-August of 1987. At this time we expected fish from the Strait of Georgia to be arriving in Hecate Strait, and few juvenile pinks are produced from Strait of Georgia tributaries in odd years. A partial explanation for the high abundance of pinks in 1987 is the fact that survival of pink eggs was unusually high in central coast rivers in the winter of 1986-1987. Increasing pink egg to fry survival to 30% in 1986/87 greatly improves the correspondence between observed and predicted species composition for July but does not help the comparison for August (Table 2). Sensitivity analysis of model predictions suggests that the correspondence between predicted and observed species composition can be improved somewhat by reducing the rate of northward movements of pinks and chums.

During early July pink and chum were the smallest of the salmon (102-112 mm), sockeye somewhat larger (116-132 mm), coho larger still (187-194 mm) and chinook largest of all (243-252 mm) (Table 3). Sizes predicted by the migration model were similar to the actual sizes for sockeye, pink, and chum, although the sizes of pink and chum were underestimated somewhat. The model underestimated the size of coho by about 30 mm, however, and chinook by more than 160 mm. The sizes of all species in August were

considerably underestimated by the model (Table 3). In the case of chinook, all the specimens captured were yearling smolts whereas the model was making predictions for underyearling smolts. Consequently, it is not surprising that predicted sizes were considerably smaller than observed. In the case of the other species the result suggests that growth rates in the model are too slow.

Sampling in Hecate Strait has revealed high abundance of juvenile salmon during the summer months. Comparison of catch data with predictions of a coastal migration model suggest that some parameters of the model are incorrect and these will be adjusted to improve the fit between observation and prediction. Future work will include analysis of salmon diets and assessment of the role of juvenile salmon in the Hecate Strait ecosystem.

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Table 1. Catches of juvenile salmon and other species in southeastern Hecate Strait in 1986 and 1987.

	July 7-11/86	July 31-Aug 2/86	July 3-7/87	Aug 13-20/87
Species	28 sets	22 sets	31 sets	21 sets
Pink	1075	1830	21229	3604
Chum	476	267	3405	94
Sockeye	46	145	713	114
Coho	272	118	368	96
Chinook	14	10	4	9
Herring	0	61	409	130
Dogfish	3	3	144	0
Rockfish*	18	13	5	3
Sablefish	5	0	0	0

*All yellowtail except for 1 black rockfish.

Table 2. Species composition of salmon (%) in catches and as predicted by a coastal migration model. Bracketed predictions for 1987 assume 30% egg to fry survival of pink salmon. (+) indicates catches of <1%.

	July 7-11/86		July 31-Aug 2/86		July 3-7/87		Aug 13-20/87	
Species	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
Pink	61	50	78	59	83	68(86)	92	27(40)
Chum	27	25	11	20	13	19 (9)	2	54(44)
Sockeye	4	24	5	19	3	12 (6)	3	15(12)
Coho	7	1	5	1	1	1 (+)	3	3 (3)
Chinook	+	+	+	1	+	+ (+)	+	2 (2)

Table 3. Fork lengths (mm) of salmon caught in Hecate Strait and lengths predicted by a coastal migration model.

	July 7-11/86		July 31-Aug 2/86		July 3-7/87		Aug 13-20/87	
Species	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
Pink	102	99	137	115	101	94	143	123
Chum	109	97	141	116	112	91	162	126
Sockeye	132	131	139	138	116	127	150	140
Coho	194	169	213	192	187	149	240	202
Chinook	243	84	214	96	252	83	243	107

Fig.1. Sampling sites on the July 3-7, 1987 cruise to Hecate Strait: ▪ - July 3; △ - July 4; + - July 5; * - July 6; × - July 7.

Fig.2. Sampling sites on the August 13-14 and August 19-20, 1987 cruises to Hecate Strait: ▪ - August 13; △ - August 14; + - August 19; * - August 20.

A. V. Tyler and W. R. Crawford

A second fitting for a recruitment model of Pacific cod (Gadus macrocephalus) in Hecate Strait, British Columbia

In an earlier paper we showed that most of the variance in a recruitment time series could be explained by a combination of advection, ambient temperature (both measured at the time of year that Pacific cod were in their larval stages), and adult stock size (Tyler and Westrheim 1986). In another paper we showed that the presence of herring as prey could be taken as an alternate model for explaining trends (Walters et al. 1986). Our objective in the present study was to combine these earlier models into a single modelling framework, and explore the relative contributions of the factors. The framework that we used was the Schnute-McKinnell response surface analysis. We first developed a better index of advection (transport), and then used a lighthouse temperature time series for sea surface temperature closer to the spawning area. We also reformluated our hypotheses about predation by cod. For fitting the response surface we used a twenty-year data series from 1962 to 1981, inclusive. We reserved data for the years 1982 through 1985 for predicting recruitment from models fitted to data from the previous 20 years, with the prior knowledge that 1985 was a particularly strong year-class. Our five hypotheses were: (1) recruitment decreased with increasing northward transport rate during the period when a cod brood was in the larval stage; (2) recruitment was related to ambient temperature at the time of hatching as a dome-shaped curve with a peak between 5.5 and 6.5°C; (3) that there was a dome-shaped curve relating recruitment to adult stock size; (4) that recruitment was positively related to the abundance of juvenile herring hatched in the same year as the cod brood because young herring were eaten by young cod, consequently increasing their growth rate and hence, survival; (5) that the recruitment was positively related to the summed abundance of age-0 and age-1 herring one year prior to cod spawning, because when prespawning cod feed well they produce a stronger year-class. The northward transport and stock-recruitment hypotheses emerged with support from both the response surface fit and prediction tests. High recruitment is apparently at times supported by the abundance of herring as a forage species, but in the absence of herring recruitment, cod production seems supported by other prey, possibly Pacific sand lance (Ammodytes).

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D. W. Welch and R. P. Foucher

Influence of variation in length-at-maturity on the population productivity of Pacific cod (Gadus macrocephalus)

Population size and productivity in Pacific cod have previously been examined with reference to variations in recruitment (Tyler and Westrheim 1986; Walters et al. 1986). Our study (Welch and Foucher 1988) was designed to examine the influence of variation in length-at-maturity on population productivity, since our preliminary analysis (Welch and Foucher 1986) suggested that large changes in the median length at which females became sexually mature had occurred. Such changes in maturity rates have substantial potential for influencing population productivity, and thus the resilience of a population to fishing.

Previous studies of maturation in fish populations generally depended on fitting smooth curves to the maturity data using probit analysis. However, this method ignores the binomial distribution of the errors in maturity observatons and, more importantly, treats all maturity-at-length observations equally, irrespective of individual sample sizes. Because one of the key questions in analyzing variations in maturity between samples (years or areas) is whether the variation is real or simply due to chance processes, we first developed a maximum likelihood technique which explicitly takes these concerns into account.

We found that estimated maturity-length relationships for females sampled in 1980 from three different grounds within Hecate Strait (White Rocks, Two Peaks-Butterworth, and Reef Island) showed substantial differences, as did the between-year variation in length-at-maturity for fish sampled from the White Rocks ground. Assuming constant somatic growth rates, these differences corresponded to shifts of slightly more than one year in the median age-at-maturity, and are large enough to have substantial influences on population productivity. We calculate that these shifts increase the instantaneous population growth rate by up to 0.25 yr^{-1} in years when maturation occurs at smaller body size. This corresponds to an increase of over 50% in the sustainable fishing mortality rate, a very large and economically important increase.

To date we have very little understanding of why these changes in rates of maturation have occurred, or why fish sampled from different grounds within Hecate Strait exhibit different maturity schedules. A lack of information on the age-structure of this population precludes direct assessment of whether these changes were in some way associated with variations in somatic growth rates. We also have little understanding of the way in which environmental changes influence maturation rates. Given the large influence of the observed changes in maturity of population productivity, we feel that further studies of these processes may have potentially important results.

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